Soft QCD Results from ATLAS and CMS

Moriond QCD, La Thuile, 25 March 2011

Claudia-Elisabeth Wulz
Institute of High Energy Physics, Vienna, Austria
On behalf of the ATLAS and CMS Collaborations
Topics

Properties of minimum bias events
- transverse momentum, pseudorapidity and event-by-event multiplicity distributions of charged particles

Underlying event characteristics
- from charged particle tracks (ATLAS, CMS)
- from calorimeter information (recent ATLAS analysis, not part of talk)
  Studied observables (non-exhaustive):
  charged particle multiplicity density
  charged particle scalar $p_T$ density
  charged particle mean $p_T$
  angular distributions

Strangeness production

Particle correlations
- Bose-Einstein correlations
- short-range and long-range angular correlations in pp and Pb-Pb events
Minimum Bias, Underlying Event

Ideally Minimum Bias events are those recorded with a totally inclusive trigger. The exact definition depends on the experiment, in particular the trigger. Usually Minimum Bias only refers to non-single diffractive (NSD) events. Underlying event comprises all particles except the (hard) process of interest. It has components from multiple semi-hard parton scattering processes and soft components from beam-beam remnants. The region transverse to the dominant momentum flow is most sensitive to the underlying event.

ATLAS Min. Bias Trigger Scintillators (MBTS)
2 stations at $z = \pm 3.56$ m, $2.09 < |\eta| < 2.82$, $2.82 < |\eta| < 3.84$

Leading track or (track) jet direction

Beam Pickup Timing for experiments (BPTX)
$z = \pm 175$ m, time resolution 0.2 ns

CMS Beam Scintillator Counters (BSC)
$z = \pm 10.86$ m, $3.23 < |\eta| < 4.65$
Transverse momentum spectra

Inclusive invariant cross-section

\[ E \frac{d^3\sigma}{dp^3} = F(x_T)/p_T^n(x_T, \sqrt{s}) = F'(x_T)/\sqrt{s}^n(x_T, \sqrt{s}) \]

CMS PAS QCD-10-008

\( x_T = 2p_T/\sqrt{s} \)
Minimum Bias pseudorapidity distributions

Charged particle multiplicities versus pseudorapidity at 900 GeV and 7 TeV

\[ \frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta} \]

\( n_{ch} \geq 1, p_T > 500 \text{ MeV}, |\eta| < 2.5 \)

ATLAS \( \sqrt{s} = 0.9 \text{ TeV} \)

ATLAS \( \sqrt{s} = 7 \text{ TeV} \)

**Data Uncertainties**

**MC / Data**

[Graphs showing data and theoretical predictions for charged particle multiplicities versus pseudorapidity at 900 GeV and 7 TeV.]

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hep-ex 1012.5104v2, accepted by New J. Physics

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Minimum Bias multiplicity distributions

\[ n_{ch} \geq 2, \ p_T > 100 \text{ MeV}, \ |\eta| \leq 2.5 \]

900 GeV

7 TeV

hep-ex 1012.5104v2, accepted by New J. Physics
Charged particle distributions

Transverse regions

Strong growth of underlying event activity with $\sqrt{s}$. PYTHIA Z1 describes the distributions and the $\sqrt{s}$ dependence well.

CMS PAS QCD-10-010
Charged particle multiplicity density

Transverse region

Two-fold increase in multiplicity for $p_T > 0.1$ GeV compared to $p_T > 0.5$ GeV

All models underestimate the multiplicity by at least 10-15%, but PYTHIA DW comes closest for $p_T > 0.5$ GeV. HERWIG/JIMMY produce more particles between 100 MeV and 500 MeV than other models.

*hep-ex 1012.0791v2, submitted to Phys. Rev. D*
The transverse region plateau characterizes the mean contribution of the underlying event to jet energies, whereas in the toward and away regions jet-like profiles are present. PYTHIA DW describes both regions best. Other Monte Carlo programs describe the transverse region in particular quite poorly.

hep-ex 1012.0791v2, submitted to Phys. Rev. D
Charged particle mean $p_T$ at 900 GeV and 7 TeV

Increase of underlying event $<p_T>$ by about 20% from $\sqrt{s} = 900$ GeV to $\sqrt{s} = 7$ TeV.

*hep-ex 1012.0791v2, submitted to Phys. Rev. D*
Angular distributions

\[ p_T > 0.5 \text{ GeV, leading particle excluded} \]

\[ \phi \text{ distribution (} \Delta \phi \text{ wrt to the leading particle) of charged particle multiplicity densities} \]

Significant shape difference between data and MC. With increasing \( p_T^{\text{lead}} \), jet-like structure develops. PYTHIA tunes predict stronger correlation in toward region.

\[ \phi \text{ distribution (} \Delta \phi \text{ wrt to the leading particle) of } p_T \text{ sum densities} \]

\hspace{1cm}

hep-ex 1012.0791v2, submitted to Phys. Rev. D

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Monotonic increase of $<p_T>$ with $N_{ch}$ in transverse and away regions. In the toward region, for $N_{ch} > 5$ a jet-like structure forms and $<p_T>$ rises weakly. PHOJET gives best description at 7 TeV.

*hep-ex 1012.0791v2, submitted to Phys. Rev. D*
Strangeness production ($K_S$, $\Lambda$, $\Xi$)

CMS

$\sqrt{s} = 7$ TeV

Yield: $6534 \times 10^3$
Mean: $497.8$ MeV/c$^2$
Avg $\sigma$: $8.2$ MeV/c$^2$

$480 \mu$b$^{-1}$

CMS

$\sqrt{s} = 7$ TeV

Yield: $34.4 \times 10^3$
Mean: $1322.1$ MeV/c$^2$
Avg $\sigma$: $4.1$ MeV/c$^2$

$480 \mu$b$^{-1}$

hep-ex 1102.4282v1, submitted to JHEP
Strangeness production ($K_S$, $\Lambda$, $\Xi$)

CMS

N stays approximately constant for both centre-of-mass energies.

hep-ex 1102.4282v1, submitted to JHEP
Bose-Einstein correlations

Pairs of same-sign charged particles with 0.02 GeV < Q < 2 GeV are studied.

\[ \mathcal{R}(Q) = \frac{R}{R_{MC}} = \left( \frac{dN/dQ}{dN_{ref}/dQ} \right) / \left( \frac{dN_{MC}/dQ}{dN_{MC,ref}/dQ} \right) \]

Reference sample: opposite-sign pairs, mixed events etc.

\( \lambda \) ... correlation strength

\( r \) ... radius of effective space-time region emitting bosons with overlapping wave functions

\( \Omega \) ... Fourier transform of the region defined by \( r \)

\[ Q = \sqrt{-\left( p_1 - p_2 \right)^2} \]
Anticorrelations between same-sign charged particles are observed for $Q$ values above the signal region.

$$R(Q) = C[1 + \lambda(\cos[(r_0 Q)^2 + \tan(\alpha \pi/4)(Qr)^\alpha]e^{-(Qr)^\alpha})](1 + \delta Q)$$

**CMS - $\sqrt{s} = 7$ TeV**

**CMS - $\sqrt{s} = 0.9$ TeV**

**CMS**

- $\sqrt{s} = 0.9$ TeV
- $\sqrt{s} = 7$ TeV

$\Delta$ ... depth of the dip in the anticorrelation region

**hep-ex 1101.3518v1, submitted to JHEP**

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Near-side long-range correlations in pp data

First surprise in LHC data!

CMS pp 7 TeV

Ridge does not come from short range correlations such as resonances, near-side jet peaks, away side correlations of particles between back-to-back jets or Bose-Einstein correlations.

Pronounced structure (ridge) in high-multiplicity events for $2.0 < |\Delta \eta| < 4.8$ and $\Delta \phi \approx 0$
Long- and short-range correlations in ion data

Short-range ($0<|\Delta \eta|<1$): Jet + Ridge

Long-range ($2<|\Delta \eta|<4$): Ridge

Ridge most evident for $2 \text{ GeV} < p_T^{\text{trig}} < 6 \text{ GeV}$, but disappears at high $p_T$. 
• Understanding of soft QCD contributions is crucial for new physics searches and precision measurements of Standard Model processes.

• Pre-LHC Monte Carlo tunes do not describe the data well in all aspects. Much more tuning is needed.

• Strangeness production has been investigated and Bose-Einstein correlations have been studied in detail.

• Interesting long-range correlations have been observed, both in proton and heavy ion data.